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Very High Temperature Gas Cooled Reactor Systems

(VHTR)

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Agenda

- Concept Definition
- Mission & Importance
- R&D Needs
- Worldwide Involvement
- First Steps
- Discussion

Very High Temperature Reactor Systems (VHTR)

- Four concepts submitted
- General features of VHTR--
  - >900 C coolant core exit temperature
  - prismatic core, 600 MWth, LEU once-through cycle
  - could be pebble bed or prismatic core
- Shows promise for
  - Gains in sustainability and flexibility
  - Significant advance towards safety goals
  - Comparable economics
  - Bridge to hydrogen economy

Very High Temperature Reactor Concepts
General Description

Gas Cooled Reactor Concept Sets (TWG-2)

- Modular Pebble Beds (PBR)
- Prismatic Modular Reactors (PMR)
- **Very High Temperature Reactors (VHTR)**
- Gas Fast Reactors (GFR)

VHTR concepts extend performance capability and establish envelope of advanced fuel and materials research for gas cooled systems

- Coolant outlet temperature -- > 900 C
- Fuel operating temperature -- > 1250 C

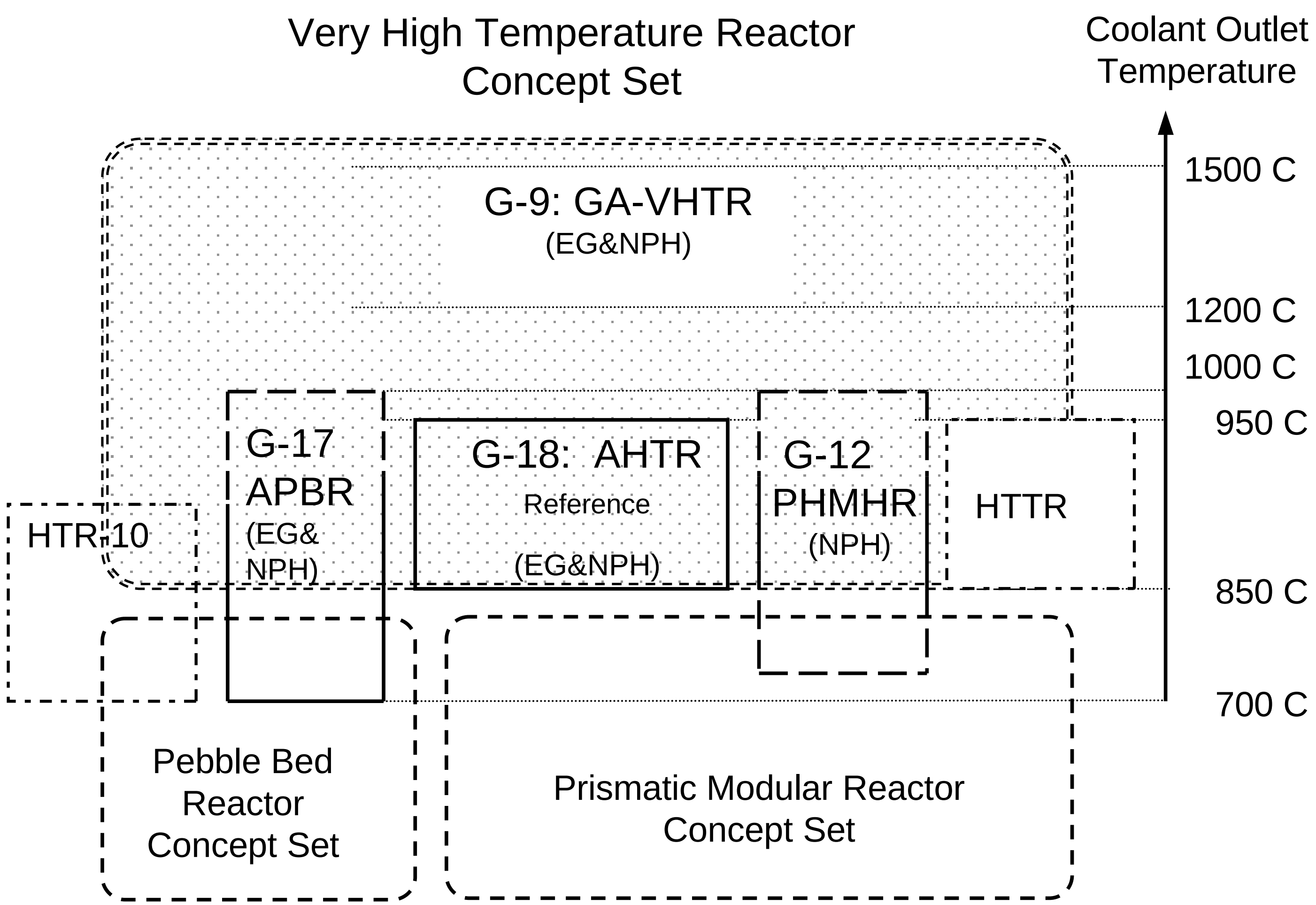
Coolant temperature ranges -- LWR ~ 320 C, CO_2 – 400-600 C, LMFBR 500 – 700 C, Gas 700- 950 C

VHTR concept set (4) -- GTMHR, Annular Pebble Bed (APBR), VHTGCR, A-HTR (HTTR)

Very High Temperature Reactor Concepts

	VERY HIGH TEMPERATURE CONCEPT			
	G-18 (A-HTR) REFERENCE	G-12 (MHR)	G-17 (APBR)	G-9 (VHTGCR)
FUEL **- Fuel** **- Fuel Particle Coating**	**LEU Th, Pu** **SiC, ZrC**	**LEU/Th, Pu/U, Pu/Th** **SiC**	**LEU**	**LEU** **ZrC**
REACTOR **- Core Type** **- Thermal Power** **- Power Density** **- Fuel Burn-up** **- Refueling Period** **- Coolant Conditions** **- Inlet/Outlet Temperature** **- Outlet Pressure**	**Pin-in Block** **600MW** **6MW/m^3** **-150GWD/ton** **2-6 years** **560/850 C** **630/950 C** **-6.8MPa**	**Multi-hole Block** **600MW x 4 Modules** **6.6MW/m^3** **-120GWD/ton** **Outlet:-1000 C**	**Pebble** **300-600MW** **120-200GWD/ton** **250/(700-1000) C** **5-8MPa**	**Not specified** **-** **-** **-** **-** **Outlet: 1200-1500 C** **-**
APPLICATION	**H2 Production**	**Process Heat** **H2 Production**	**Cogeneration** **Process Heat, H2**	**H2 Production**
FUEL CYCLE	**Once through**	**Once-through**	**Once-through**	**Once Through**

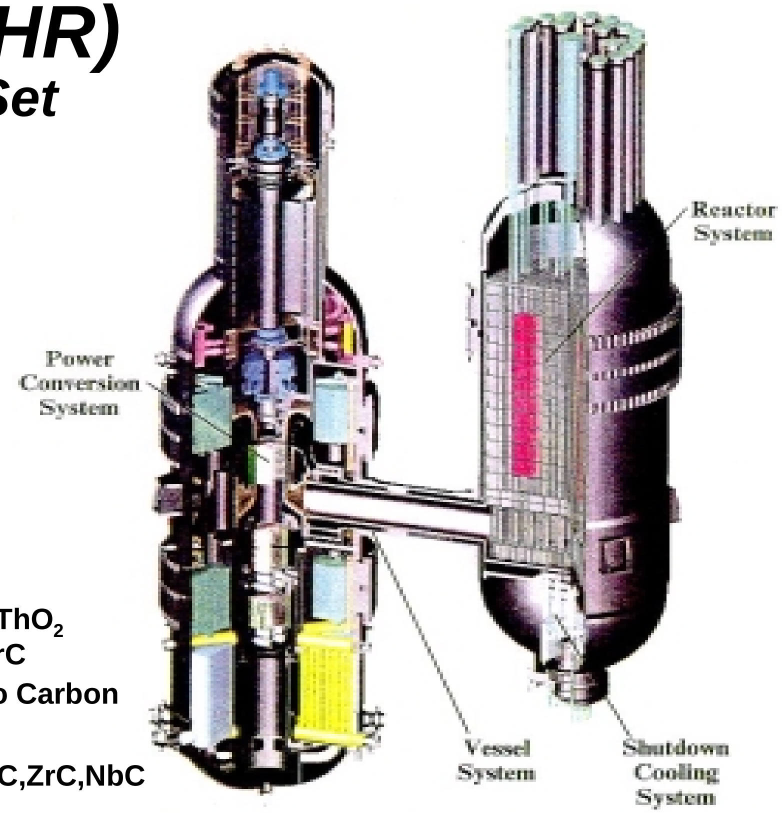
Temperature Capability of Concepts



EG-Electrical Generation   NPH-Nuclear Process Heat Applications

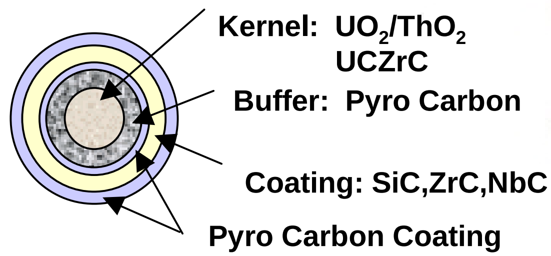
Modular Helium Reactor (MHR)

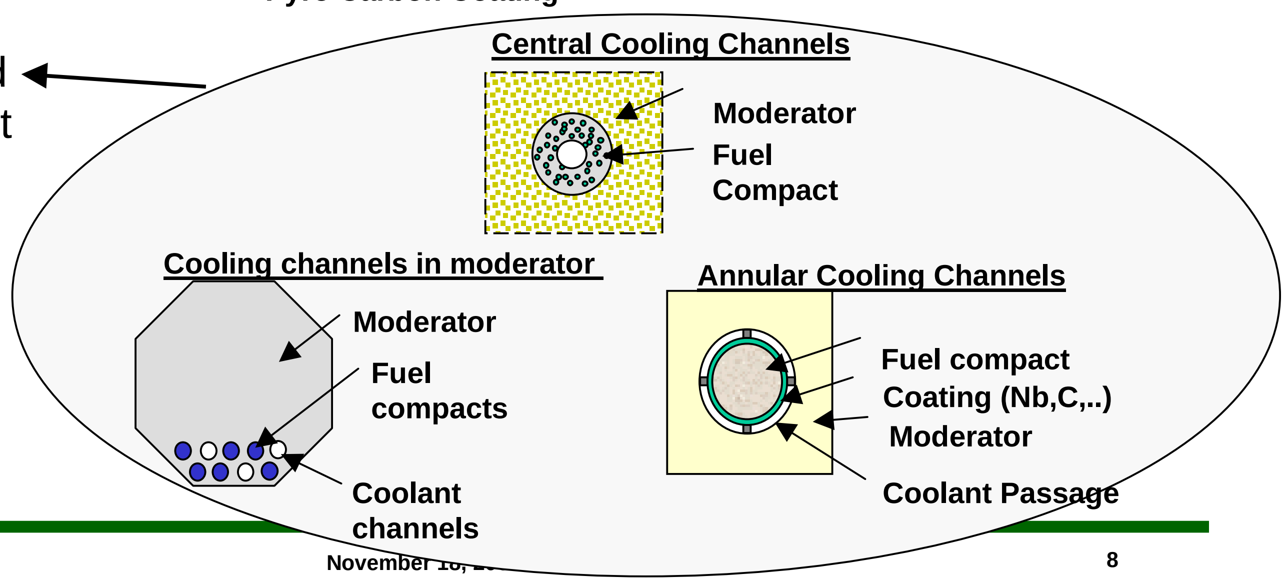
Reference Concept for VHTR Concept Set



- **Based on prismatic (GTMHR) design connected to steam reformer/steam generator -- non electric**
- **High temperature source for range of process heat applications**

- **High Temperature Considerations**
  - Advanced particle coatings for FP retention at elevated temperatures
  - Advanced fuel materials (carbides, nitrides, cermets,etc)
  - Fuel element design for reduced temperature drop - fuel to coolant
  - Control materials and design
  - Structural materials
  - Heat exchanger / recuperator materials and design

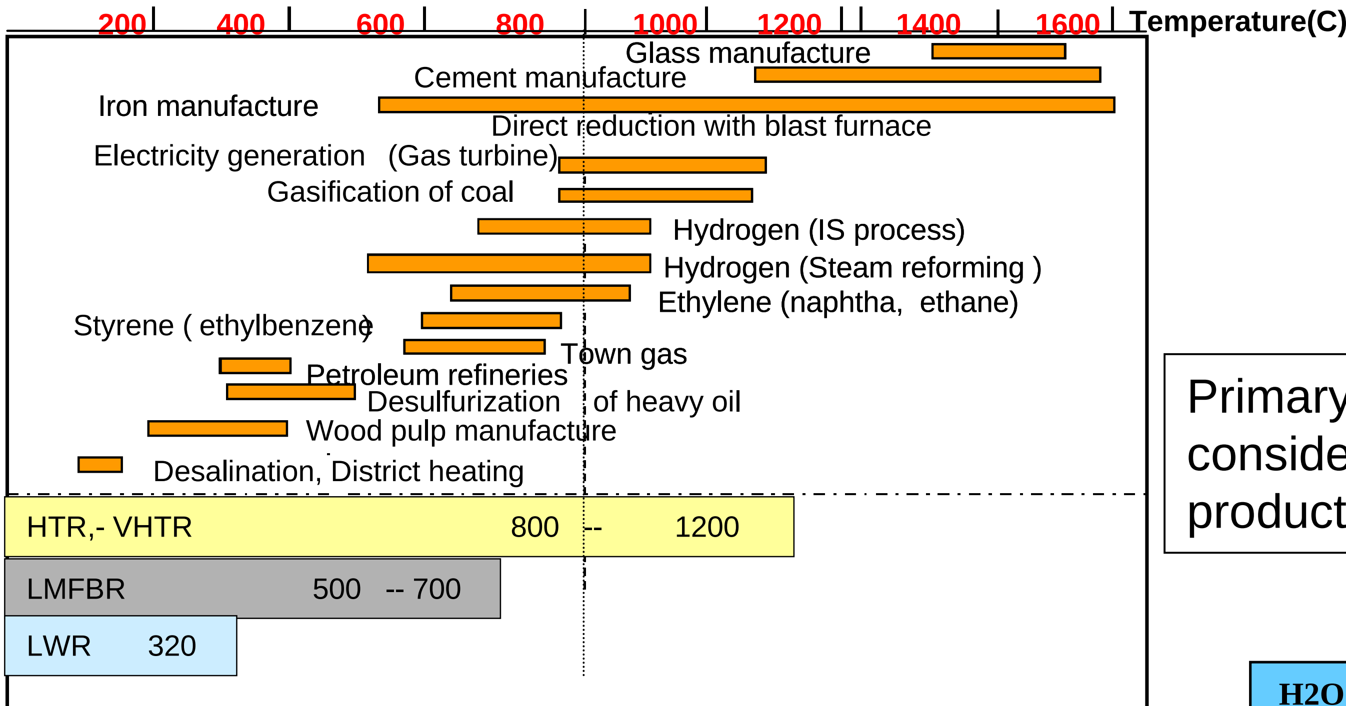




VHTR Mission & Importance

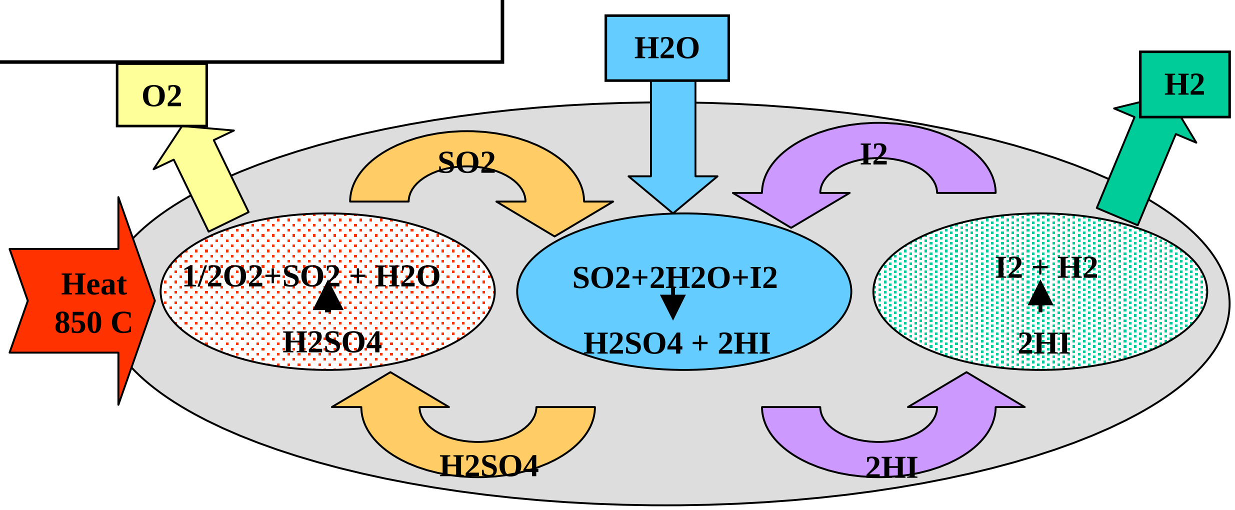
- 30 % of world primary fuel use is to generate electricity
- 17 % of electricity uses nuclear fuel
- Nuclear power can offset other primary fuels in applications other than electricity
- VHTRs may significantly reduce liquid and gaseous fossil fuel demands

High Temperatures Enable a Range of Process Heat Applications



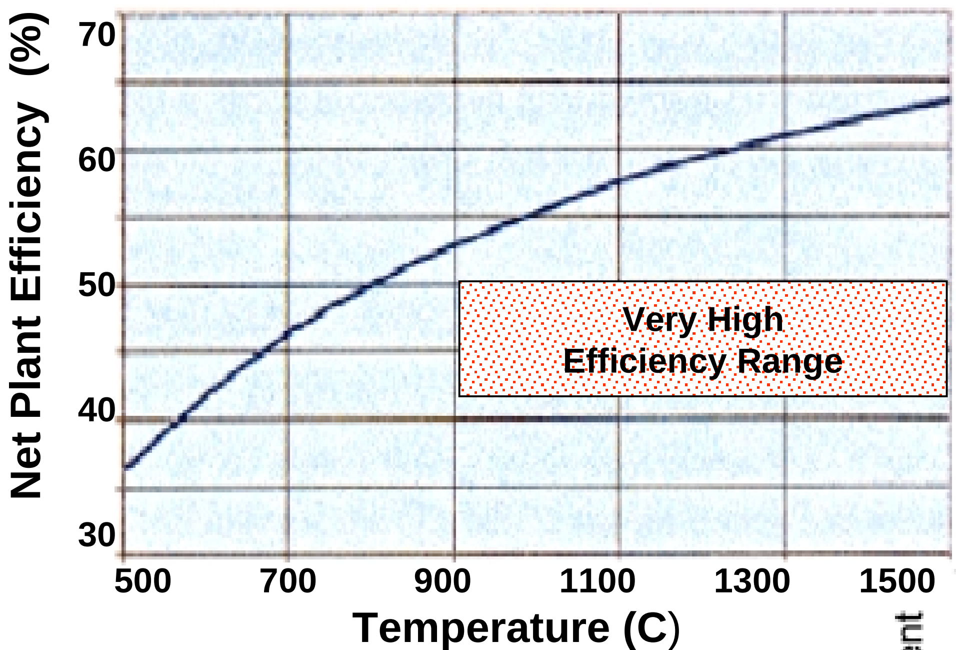
Primary nuclear application considered for VHTR – H2 production

Thermochemical cycles for Hydrogen production >750 C

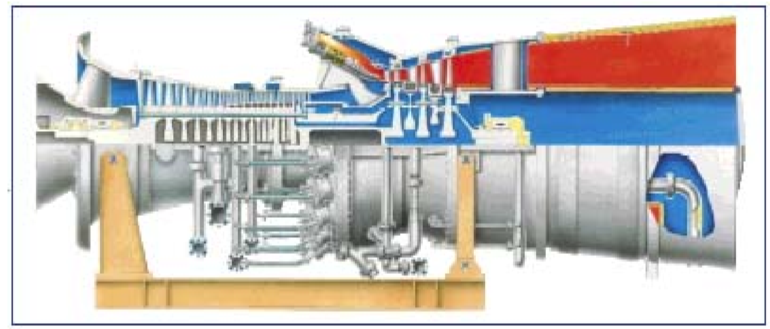


High Outlet Temperatures Provide Increased Electrical Conversion Efficiency

High efficiency benefits all aspects of system performance

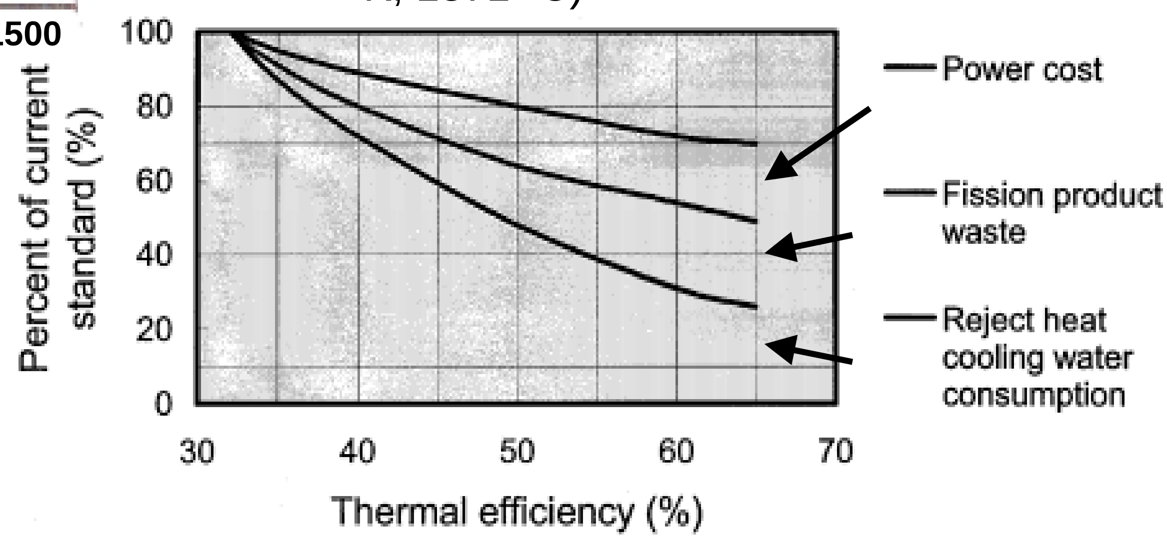


Efficiency vs Turbine Inlet Temperature for Recuperated Brayton Cycle)

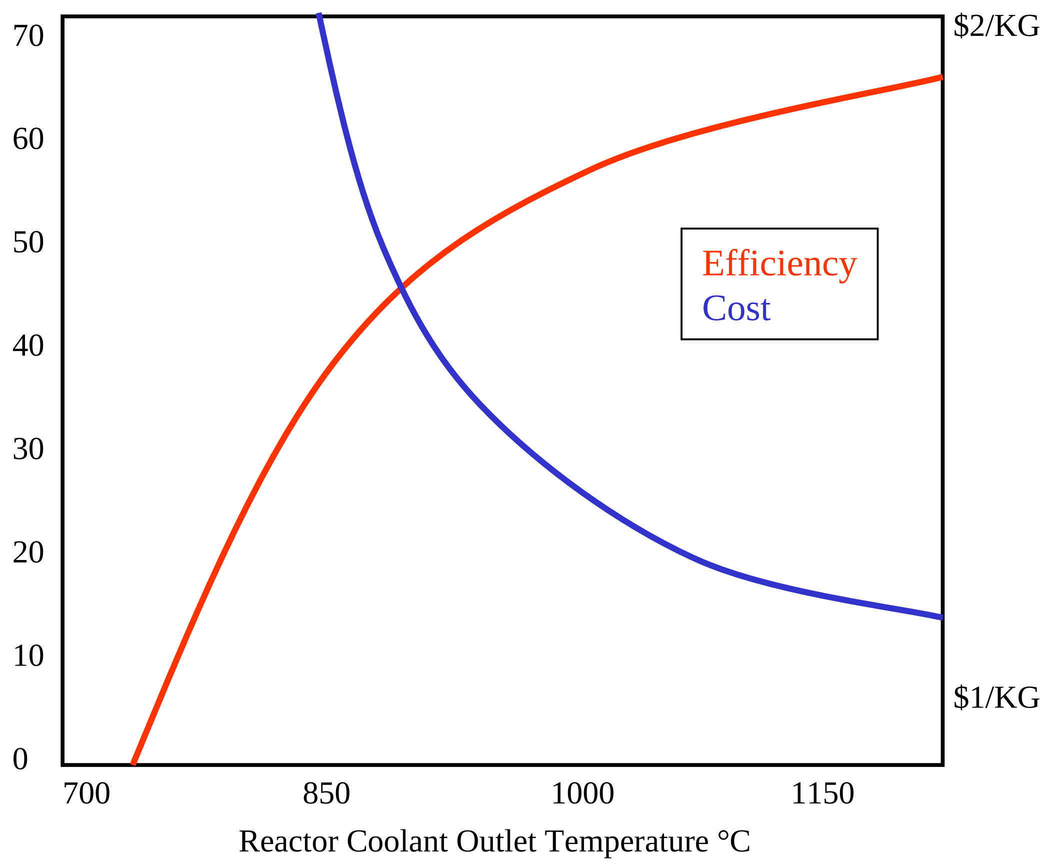


GE Power Systems MS7001FB

- Single crystal Technology (GE's jet engines)
- 2500° F-class firing temperature (1644 K, 1371 ^{o}C)

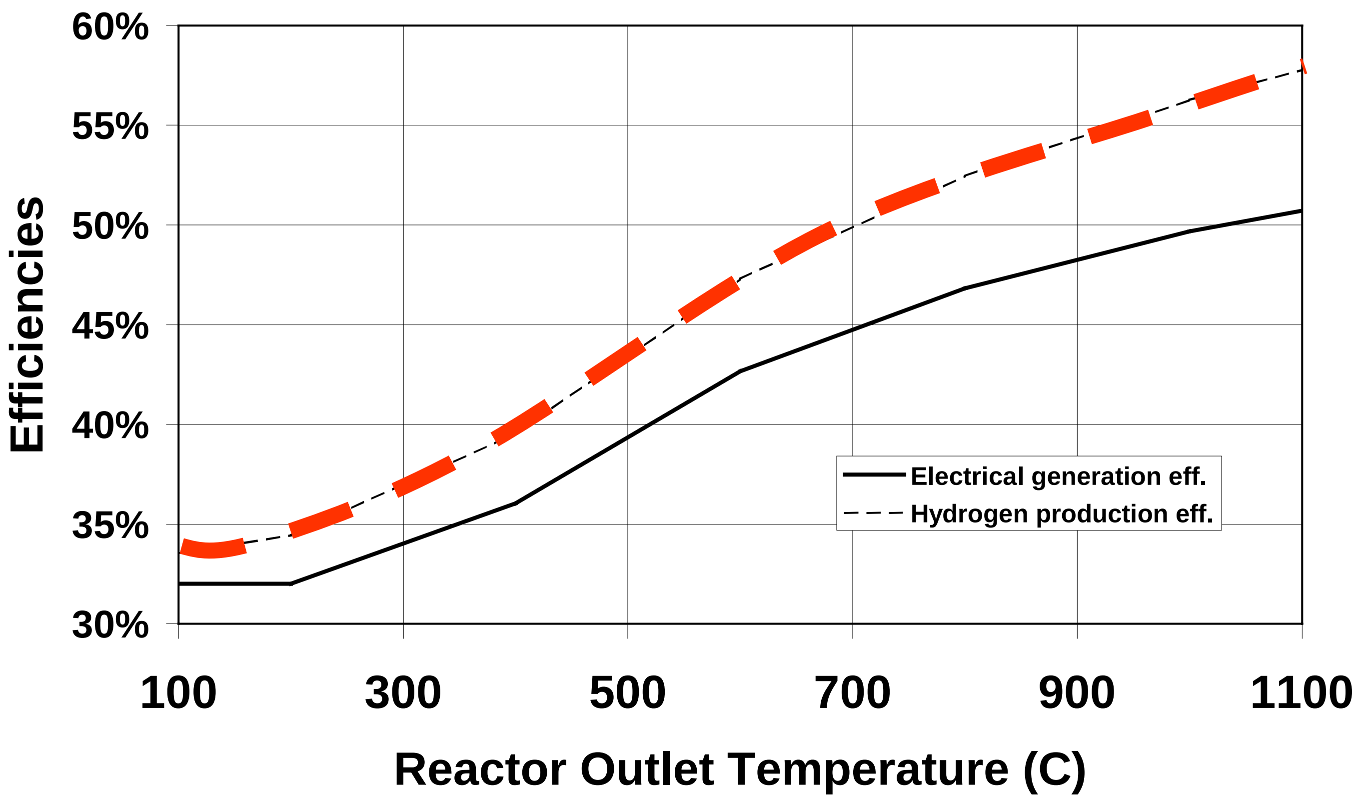


VHTR Hydrogen Production Efficiency
S-I Cycle



VHTR Hydrogen Production Efficiency Steam Electrolysis

Efficiencies of High Temperature Electrolysis



Very High Temperature Reactor Issues

- Cost / Benefit -- increased performance at higher temperatures versus potential impacts on cost/reliability
- Proximity of high temperature process heat application to nuclear system – safety, heat transport
- Materials lifetime at elevated temperatures

VHTR Builds Upon Near Term Gas Reactors

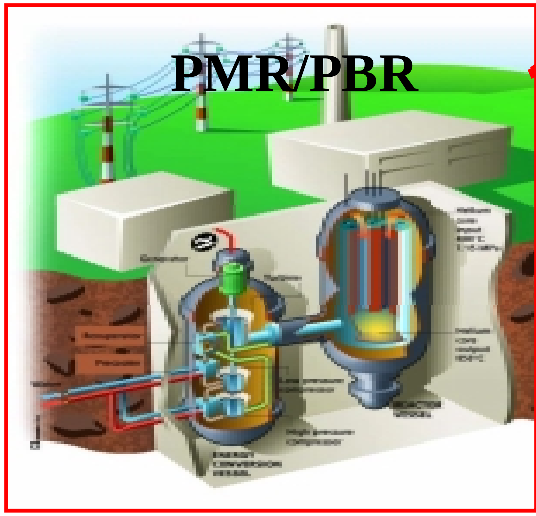
R & D
- **Fuel particles**
- **Materials**
- **He systems technology (850°C)**
- **Computer codes**
- **Fuel cycle**

GFR

VHTR

Improved sustainability

> 950°C for VHT heat process



R & D
- **Fast neutron fuel**
- **Fuel cycle processes**
- **Safety systems**

R & D
- **VHT materials**
- **IHX for heat process**
- **ZrC coated fuel**
- **I-S cycle H2 production**

VHTR R&D Needs

- Fuel
  - F1: Demonstrate TRISO fuel to required quality level and performance. Test in prototypic reactor conditions and in accident conditions. Fabricate test articles. Include Cs and Ag diffusion measurements and control.
  - Extend to High Burnup (>200,000 MWD/MTU)
  - F2: For core exit coolant temperatures above 900 °C, fuel temperatures above 1300 °C may be needed. Examine higher temperature coatings (e.g. ZrC). Repeat F1 development.
  - Fuel Development is a viability issue for all Gen IV and near term gas reactors (in the United States)

VHTR R&D Needs (Fuel Cycle)

- Fuel Cycle
  - FC1: Fabrication Process needs to be developed for fuel
    - » Coating process definition and demonstration (inc. ZrC)
    - » Kernel fabrication process demonstration
    - » Process line components and QC methods selection
    - » In-core irradiation testing to qualify fuel (see fuel section)
  - FC2: Spent Fuel characteristics need to be demonstrated
    - » Determine long term repository behavior of fuel
    - » Develop pretreatment and conditioning methods
    - » Develop closed and open cycle separation technologies.

VHTR R&D Needs (Rx Systems)

- Existing control rod materials not well suited to high temperatures--Develop, test, and design new materials (graphite fiber, etc.)
- High Temperature materials needed for key components
  - Reactor vessel material selection and qualification
  - Hot gas ducts and components materials
  - Recuperator materials
  - Insulation materials
  - Expansion joint materials
  - Intermediate heat exchanger materials
  - High temperature concrete for RCCS
  - Impure helium effects on materials testing.
  - HT Isolation Valve Materials
- Graphite Fabrication and Qualification
- Graphite Disposal or Reuse
- Decommissioning Issues

Roadmap GENERATION IV nuclear energy systems

VHTR R&D Needs (Balance of Plant)

- High Temperature materials for turbine are needed
- Matching of process heat application to heat source required
- Hydrogen production processes need definition
- Compressors, catcher bearing, magnetic bearing, etc. require trade studies
- Demonstrate Rx/Process Interface with IS Process
- Engineering Demonstration of H2 Production

VHTR R&D Needs (Safety & Performance)

- Air ingress behavior needs confirmation
- TRISO fuel performance needs demonstration
- Reactivity insertion events need to be assessed
- Transient models need qualification
- Thermal mixing at core outlet uncertain
- RCCS tube failure needs to be modeled
- Effect of direct cycle on existing system codes required
- FP transport in RCS needs definition
- PRA Model may need to be defined
- Collocation issues of process applications and nuclear supply

VHTR R&D Needs
(Economics, Codes)

- Modularity benefits need quantification
- Plant equipment reliability needed
- Reduced staffing may improve O&M costs
- Need market assessment for H2 or other PHA products

- Core neutronics codes needed
- T&H codes needed

Worldwide Involvement

- Europe-- HTR-TN
- SINTER Network
- JAERI-- HTTR
- Significant US Industrial Growth in H_2 Production
- Entergy Interest in H_2 -MHR
- NERI and INERI Projects-- University of Kentucky, Texas A&M, General Atomics, SNL, INEEL, ORNL, CEA
- Ongoing GCR Development is supportive of VHTR-- South Africa, Russia, ROC (HTR-10)

First Steps

- Refine R&D Scope
  - VHTR System Concept Study
  - Program Plan
- Conduct Technical Information Exchange
  (May be in conjunction with International Conference)
  Invite Worldwide Interested Contributors and Users
- Establish International Partnerships—government agencies, laboratory and industrial

Discussion